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Self-Report and Ocular Measures of Fatigue in U.S. Army Apache Aviators Following Flight

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13. ABSTRACT *(Maximum 200 words)*
AH-64 Apache helicopter pilots fly the aircraft using a monocular helmet-mounted display that provides imagery from two separate forward-looking infrared sensors mounted on the nose of the aircraft. Studies have documented complaints of fatigue, headaches, and visual problems associated with the use of this sighting system. The goals of this study were 1) to quantify possible flight-induced fatigue in Apache aviators and 2) to evaluate minimally intrusive neurophysiologic measures of fatigue for potential use in operational environments. Methods: Using a pre-post design, we assessed self-reported levels of alertness, physical, cognitive, and visual fatigue and ocular indices of fatigue obtained using an instrument specifically designed to capture various eye responses. Fifty-three aviators contributed data to this study. Results: Significant differences in all pre- and postflight ocular responses were observed. Pupil size and constriction latency increased while constriction amplitude and saccadic velocity decreased. Significant pre- and postflight differences also were seen on all self-report measures. Pilots reported being less alert and more fatigued following flight. Conclusions: We found that flight in an AH-64 Apache was a significant factor in producing changes in ocular and self-report measures similar to those produced by sleep loss.

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Introduction

The U.S. Army's AH-64 Apache attack helicopter has been fielded since the early 1980's. It is a tandem-seated aircraft with the pilot occupying the rear seat and the copilot/gunner occupying the front seat. Both pilots fly and perform fire-control procedures using a monocular helmet-mounted display known as the Integrated Helmet and Display Sighting System (IHADSS). The IHADSS provides pilotage and fire-control imagery from separate forward-looking infrared sensors mounted on the nose of the aircraft. As pilots gained experience with the use of the monocular system (see figure), complaints of visual problems began to arise. Hale and Piccione (1989) conducted the first survey of AH-64 Apache aviator experience with the IHADSS. The study documented aviator complaints of fatigue and headaches. A number of subsequent studies (Behar et al., 1990; Crowley, Rash, and Stephens, 1992; Rash et al., 2001) have documented similar issues. With the cancellation of the Comanche program, it has become apparent that the Apache will remain the main attack helicopter within the U.S. Army for the foreseeable future.

Figure. AH-64 Integrated Helmet and Display Sighting System (IHADSS).

Future Force Warrior (FFW), the Army's flagship science and technology initiative, recognizes the possibility that soldiers may be called upon to conduct missions as long as 72 hours. During extended missions or high op-tempo conditions, aviators, ground vehicle operators, and ground troops must continue to assess battlefield conditions and respond quickly and correctly to an ever changing environment. FFW also has identified the need to optimize cognitive and physical capabilities during these periods. Thus, a system that quickly and reliably evaluates cognitive function and alertness becomes of paramount importance when the success or failure of a single individual is mission critical. Some of the most objective indicators of alertness or sleepiness currently available are obtained from measurements of brain activity. These measurements (i.e., electroencephalography (EEG)) are used in both research and clinical setting to examine a host of issues such as sleep disorders, brain damage, alertness, and drug effects (Niedermeyer and Lopes DA Silvia, 1993). However accurate these measures are, it is unlikely that soldiers will be wired for continuous EEG recording during combat and very improbable that lengthy cognitive test batteries will be of practical use under battlefield conditions.

A variety of self-report measures have been developed to study fatigue, sleepiness, and alertness. These measures are easy to administer and readily accepted by study participants. The Stanford Sleepiness Scale (SSS) consists of seven statements ranging from "wide awake" to "cannot stay awake" (Hoddes et al., 1973). The scale has been validated against performance measures as a function of sleep deprivation. Another very widely used measure is the Visual Analog Scale (VAS). This type of measure was initially developed for use in educational research (Monk, 1991), but also has been used in symptom measurement. The measure consists of a single horizontal line presented on a piece of paper. At one end of the line an anchoring descriptor is displayed such as "wide awake" and at the other end the opposing descriptor "about to fall asleep" is placed. Study participants are instructed to place an X on the horizontal line between the anchors to indicate the extent to which it is the best description of their current state. While measurements of sleepiness/alertness may differ, researchers have correlated objective measures of sleepiness with self-reports. It has been shown that individuals who report being tired generally show lower levels of alertness on objective EEG measures (Caldwell and Ruyak, 1998; Kelly et al., 1998).

Because EEG data are rather difficult and time consuming to collect, other physiological indices predictive of alertness and fatigue have been explored. Eye responses have been examined as a means to measure fatigue and its relationship to performance declines (Hoeks and Levelt, 1993; Russo et al., 2003; Yoss, Moyer, and Hollenhorst, 1970). One such study examining fatigue in military pilots was conducted using the electro-oculogram (EOG) and subjective estimates. Pilots began their work day at 0100 and remained awake throughout the day. At 1300 they began a 4.5 hour simulator flight. Pilots were given the USAF Subjective Alertness Measure, the SSS, and the USAF Sleep Survey Form. Results indicated that subjective reports of fatigue increased significantly over time and were positively correlated with increased flight error. A number of the components of the EOG signal were good predictors of increased error due to fatigue (Morris and Miller, 1996). Additional ocular measures that do not require volunteers to have electrodes attached, as is the case with EOGs, have been examined as means to quickly and easily quantify fatigue.

Several fatigue research groups have collected data from systems that measure ocular responses to a stationary and/or moving light flash. Bright light causes the pupil to reflexively constrict and dim light causes the pupil to reflexively dilate (Davson, 1972). Ocular responses to light such as constriction latency, constriction amplitude, and the speed of saccadic eye movement have been used to identify sleepiness and mental fatigue (Fant et al., 1998; Perry, 1998; Rowland et al., 1997; Russo et al., 2003; Schmidt et al., 1979). Pupil response latency is the time from the onset of the stimulus to the onset of pupil constriction and pupil constriction amplitude is the maximal amount of constriction that occurs following the stimuli. A saccade is the ballistic movement of the eye from one fixation to the next. A saccade is characterized by fast eye movements of up to 700 degrees per second (Barbur, 2004). Slowed saccadic velocities have been demonstrated with increased sleep loss (De Gennaro et al., 2000; Russo et al., 2003; Schmidt et al., 1979). Pupil size also has been used as an indication of a person's fatigue or cognitive state. Pupils are generally larger when people are fully rested and cognitive processing is not impaired (Hoeks and Levelt, 1993; Yoss, Moyer, and Hollenhorst, 1970). These measures

have been gaining in popularity in the research field as equipment has become smaller and portable to areas outside of the laboratory.

It has been repeatedly demonstrated that sleepiness produces physical and cognitive slowing that results in performance declines on many tasks such as driving and flying (Arendt et al., 2001; Caldwell et al., 2004; Dinges and Kribbs, 1991; Russo et al., 1998). While the physiological and self-report data may not always agree, there is evidence that many ocular and self-report measures do correlate with decrements in performance (Johnson et al., 1988). However, additional research is needed to clarify the circumstances under which some measures are more useful than others. With continued operations such as those seen in Iraq, it has become necessary to provide commanders and medical personnel with quick and reliable tests to assess fatigue in soldiers. At present, we must rely on a soldier's self-assessment of his physical and cognitive condition in the decision making process to conduct or abort a mission. As Apache aviators have consistently reported fatigue following flight, they were chosen as the study population. We assessed 1) self-reported levels of physical, cognitive, and visual fatigue; and 2) whether flight induced fatigue could be detected by oculomotor measures.

Methods

Subjects

U.S. Army Apache aviators were recruited for this study. The study protocol was approved in advance by The U.S. Army Aeromedical Research Laboratory's Institutional Review Board. Fifty-three aviators contributed data to this study. Volunteers were not paid for participation in this study. The average age of the pilots was 32 ± 7.03 years. The average number of flight hours for the group was 1462 ± 1599 hours (aircraft and simulator). During this study, 587 sets of pre-and post flight measures were obtained.

Procedures

Aviators were given a briefing which described the purpose, methods, and time commitment needed from them for this study. Those who wished to volunteer were provided with informed consent statements. All questions about the study were answered. Following the informed consent process, volunteer aviators were asked to select a four-digit personal identification number (PIN) to be used for coding basic demographic information and subsequent test data.

Each aviator was given a computerized tutorial/demonstration that explained the Fitness Impairment Tester (FIT, see description in apparatus section below). Basic demographic information was obtained and they were instructed on how and when to fill out the pre- and post flight questionnaires. Aviators were asked on to rate their alertness, mental fatigue, visual fatigue, and physical fatigue levels. Aviators were provided with the following guidance: when we ask you to rate 1) Alertness, we mean "How sleepy or awake are you currently feeling?"; 2) Mental Fatigue, we mean "How tired does you brain feel?"; 3) Visual Fatigue, we mean "How tired do your eyes feel?"; and 4) Physical Fatigue, we mean "How tired does your body feel?." On each preflight questionnaire, the aviators were also asked to estimate the number of hours

that they slept in the previous 24 hours. On the post flight questionnaire, they were asked to provide the number of flight hours logged that day.

Aviators were instructed to fill out the preflight questionnaire upon arriving at the airfield for flight duty and to take the preflight FIT test just prior to departing for the aircraft. They were also instructed to fill out the post flight questionnaire and take the post flight FIT test as soon as practical upon returning from the flight (approximately 15 minutes). A research technician was present in the briefing room during the pre- and post flight testing periods to assist aviators with the FIT machine and to answer any additional questions. Data was collected in a training environment using instructor and student pilots. Volunteers rotated through different phases of flight school during the data collection period. Flights occurred at different times of the day depending on mission profile (e.g. night gunnery phase is flown after dark) and test times were automatically recorded by the FIT machine.

Apparatus

FIT

The FIT is a self-contained, fully automated instrument specifically designed to analyze the eye for signs of neurological changes caused by drugs, alcohol, or sleepiness. The FIT detects changes in pupil size as small as 0.05 mm and movements of the eye as small as one degree (approximately the distance between these letters at a normal reading distance). To stimulate the pupil response, the FIT provides controlled flashes of light with retinal intensity that is constant regardless of pupil size. To stimulate eye movements, lighted targets are made to move along a precise path. The FIT measures the response of the eye to the light stimulus and then calculates a set of four parameters that describe the essential features of the responses. Three parameters are derived from the response of the pupil to a light flash; initial diameter (ID), constriction latency (CL) and constriction amplitude (CA). A fourth parameter, saccadic velocity (SV), is the average velocity of rotation of the eye, measured in degrees per second, as the subject responds to an abrupt change in target position. The FIT tester was placed in the room used by the aviators during pre- and post flight briefing. The room was illuminated with standard fluorescent light.

In use, each aviator entered a PIN on a keypad and looked into the FIT eye-piece. As all Apache aviators fly with the IHADDS on the right eye, all FIT tests regardless of eye dominance were conducted on the right eye. The aviator focused his right eye on a light in the center of the field of view observed through the eye port. When ready the aviator pushed a button and the FIT automatically initiated a thirty-second test sequence. The test sequence consisted of a series of light flashes during which the subject simply had to follow a moving fixation target. The aviator was informed of test completion by an audible signal. Under computer control, the FIT measured pupil diameter 60 times each second and eye position 900 times each second. The FIT machine automatically time and date stamped each set of data. The FIT machine was always operated under the same lighting conditions (normal office fluorescent). All data collection took place in the anteroom of the S2/S3 office in building 50102N, 1st BN, 14th Aviation Regiment, Hanchey Army Airfield, Ft. Rucker, AL.

Pre- and post flight questionnaires

Aviators provided responses to the same four questions prior to and after each flight. They were asked to make a mark along each of 4, 100 mm lines denoting their alertness and fatigue levels. Differences in the four FIT parameters and responses to the pre- and post flight questionnaires were examined. The four questions are listed below. Additionally, aviators reported the number of hours slept in the previous 24-hour period and the number of flight hours logged that day.

HOW WOULD YOU RATE THE FOLLOWING (Please mark on the lines below)

ALERTNESS I---I
VERY SLEEPY VERY ALERT

MENTAL FATIGUE I---I
NONE EXTREME

VISUAL FATIGUE I---I
NONE EXTREME

PHYSICAL FATIGUE I---I
NONE EXTREME

Data Analysis

We used the FIT post flight time stamp to classify the data into one of six time blocks (0001-0400 = 1, 0401-0800 = 2, 0801-1200 = 3, 1201-1600 = 4, 1601-2000 = 5, 2001-0000 = 6). Number of hours slept, number of hours flown, and time block were correlated with change scores (pretest - posttest) for each of the 587 daily self-report and ocular measures to explore possible relationships.

Examination of the oculomotor and self report data showed that some aviators took the pre- and posttests more than others (range 10 – 44 tests/subject). Those contributing the most data were likely the instructor pilots who flew on a more regular basis than the student pilots. Due to the large range of individual data contribution, pretest data were averaged for each individual and posttest data were averaged for each individual. Data were then subjected to paired t-tests. Change scores (pretest-posttest) for the averaged data also were calculated and correlated with age.

Results

Examination of the daily demographic data showed that aviators reported obtaining an average of 7.06 ± 1.5 hours of sleep in the 24 hour period prior to each flight. Additionally, aviators logged an average of 1.2 ± 0.62 hours of flight time per flight.

Daily demographic variables (number of hours slept, number of hours flown, and time block in which post flight FIT was taken) were correlated with daily change scores (pretest - posttest)

from each of the self-reported and ocular measures. As can be seen in Table 1, no high ($\geq$0.7) or moderate ($\geq$.5) degree of correlations were observed among these variables. A low, yet significant negative correlation was seen for time block and constriction amplitude change scores (r = -.328; p=.01). A low, yet significant negative correlation also was seen for time block and self-reported visual fatigue (r = -.197; p=.05). These results show that the largest changes between pre- and post flight constriction amplitude and self-reported visual fatigue were seen during the earlier time blocks which started at midnight, while the smallest changes were seen during the later time blocks which started at noon. Analyses of the change scores (pretest - posttest) from the averaged data revealed no significant correlations of age with any of the self-report or ocular measures. With 52 degrees of freedom (df) all r values were below the critical value of .273 need to obtain significance at the p=.05 level.

Table 1.
Pearson r values.

Variable Change Scores (pre – post)	Hours slept	Hours Flown	Time Block
Pupil diameter (mm)	.084	.155	.176
Constriction amplitude (mm)	-.171	.015	-.328**
Constriction latency (msec)	-.088	-.071	-.17
Saccadic velocity (deg/sec)	.086	-.005	.12
Alertness	.155	.097	.167
Mental fatigue	.-.072	-.089	-.123
Visual fatigue	-.151	-.157	-.197*
Physical fatigue	-.102	-.181	-.184

Critical values with 566 df, *p = .05 is 0.195; ** p = .01 is 0.254.

Paired t-tests were conducted on the averaged pre- and post flight data. Testing the hypothesis that mean difference (pre - post) = 0 showed that pupil diameter was significantly larger when measured post flight (Table 2). Additionally, these tests showed that constriction amplitude was significantly less, constriction latency was significantly longer and saccadic velocity was significantly slower on the post flight measures. No differences in constriction amplitude were found.

Table 2.
Paired t-tests of oculomotor measures.

Variable	Mean	SD	t (df = 52)	P(T<=t)
Preflight pupil diameter (mm)	4.861	.906		
Post flight pupil diameter	4.928	.935	-1.606	0.05
Preflight constriction amplitude (mm)	1.026	0.244		
Post flight constriction amplitude	0.946	0.235	3.751	0.000
Preflight constriction latency (msec)	299.950	18.613		
Post flight constriction latency	305.151	19.153	-3.586	0.001
Preflight saccadic velocity (deg/sec)	78.408	10.988		
Post flight saccadic velocity	75.940	10.322	5.734	0.000

Paired t-tests also were conducted on the averaged pre- and post flight self-report data (Table 3). Testing the hypothesis that mean difference (pre - post) = 0 revealed that post flight alertness was significantly lower. Mental, visual, and physical self-reported fatigue levels were significantly higher when compared to preflight values.

Table 3.
Paired t-tests of self-report measures.

Variable	Mean	SD	t (df = 32)	P(T<=t)
Preflight alertness	73.735	16.243		
Post flight alertness	70.073	18.419	1.797	0.03
Preflight mental fatigue	20.421	13.804		
Post flight mental fatigue	25.499	15.114	-4.441	0.000
Preflight visual fatigue	17.998	13.721		
Post flight visual fatigue	24.348	16.827	-5.510	0.000
Preflight physical fatigue	18.678	14.406		
Post flight physical fatigue	22.951	16.242	-3.772	0.000

Discussion

In this study, we observed significant changes in the pupil's response to light following flight in the AH-64 Apache helicopter. We found that flight produced changes in several ocular and self-reported measures of fatigue similar to those produced by sleep loss. Additionally, we saw time of day effects in constriction latencies and self-reported visual fatigue. Pre- and post flight changes were larger in subjects who flew during the late evening/early morning hours and smallest in those who flew during the afternoon and early evening. These results are consistent with many others who have reported increases in physiological and self-report measures of fatigue during the critical hours (midnight-0600) in both rested and sleep deprived subjects (Caldwell et al., 2004; Caldwell and Ruyak, 1998; Monk, 1991; Monk et al., 1989).

Studies have examined ocular measures in various sleep loss paradigms (total, partial, short term and chronic). Many have observed increased constriction latencies, decreased constriction amplitudes, and slowed saccadic velocities with increased sleep loss (Caldwell et al., 2004; De Gennaro et al., 2000; Russo et al., 2003; Schmidt et al., 1979) similar to those observed in this study. Examination of results from a sister article in the current monograph (Rowland et al., in press), shows that the changes in latency to pupil constriction and saccadic velocity in Apache aviators following flight were of comparable magnitude to what Rowland et al. found after one night of total sleep deprivation. These authors and others also reported decreases in alertness and increases in fatigue and sleepiness when measured with self-reports (Rowland et al., in press; Thomas et al., 2003). Similar changes in these measures also have been correlated with performance declines in driving and flight skills (Caldwell et al., 2004; Rowland et al., in press; Russo et al., 1998; 2003).

In contrast to the other ocular and self-report measures collected in this study, changes in pupil diameter following flight indicated increased arousal levels. The post flight increase in pupil diameter was initially puzzling. The iris, which forms the pupil, consists of a layer of cells containing pigment, and two sets of muscles. A ring shaped muscle, the sphincter, closes the pupil, and a radial set of muscle fibers, the dilator, opens it. Primary input to the sphincter is from the parasympathetic branch of the autonomic nervous system, whereas the dilator is controlled by the sympathetic branch (fight or flight). Pupil size is determined by the balance between actions of these two branches of the autonomic nervous system. It seems logical that in fatigued individuals, as arousal/alertness levels decline, sympathetic control of the dilator muscles would wane while parasympathetic control of the sphincter muscle would increase. Thus, we initially expected to see a decrease in pupil size on the post flight assessments.

However, in hindsight, given that flight can be a very exciting yet stressful event, especially for student pilots, the increase in pupil diameter does not seem that unusual. The possibility of increased endocrine activity due to the flight environment may account for this unanticipated result. As early as the 1950s, Ulf von Euler and his colleague were able to show that catecholamine secretion was related to the intensity of flight stress (von Euler and Lundberg, 1954). In later studies, intensive military flying and aerial combat maneuver flight missions (Iyer, Banerjee, Baboo, 1994; Krahenbuhl et al., 1980) and commercial and military flying in emergency situations (Krahenbuhl et al., 1985; Sive and Hattingh, 1991) were reported to enhance the secretion of sympathetic-adrenal hormones. Noradrenaline (NA) and adrenaline (A)

catecholamines secreted from the adrenal medulla have direct stimulating effects on peripheral tissues. Release of these catecholamines can produce physiological effects such as vasoconstriction, increased heart activity, inhibition of gastrointestinal tract and dilation of the pupil of the eye. It may have been that increased circulating NA and A had not returned to preflight levels within the 15 minute window from landing the aircraft to taking the post flight tests. This is also supported, somewhat, by the small change in alertness reported by the aviators. While self-reported alertness did significantly decline from the pre- to post flight measure, the change was about 5%. The changes in the other three self-reported fatigue measures were all greater than 20%.

This brings up an obvious unanswered question: "How long following flight would it take for our particular measures to return to baseline levels?." As we were collecting data in a training environment, it would not have been possible for us to obtain this information. One of the goals of this project was to assess tests which would allow quick collection of data. Underlying this issue was the use of unobtrusive methods and the desire not to interfere with the daily training schedule. It may be possible to obtain data from an operational unit that does not have such a rigid daily time schedule. Additional questions such as: "What is the impact of the monocular sighting system on fatigue?" and "How will different lengths of flight impact these measures?" also are left unanswered. However, our results tend to support the idea that while the extra ocular muscles may have been fatigued by flight in the Apache helicopter, the effects of prolonged sympathetic activation from flight may have prevented the typical pupil constriction seen in fatigued subjects.

Conclusions

The goals of this study were to quantify possible flight-induced fatigue in Apache aviators and to evaluate the usefulness of two minimally intrusive measures of fatigue. Both of these goals were met. Analyses of the objective and subjective measures of fatigue examined in this study support the retrospective data obtained from Apache aviators during the original survey studies (Behar et al., 1990; Crowley, Rash, Stephens, 1992; Hale and Piccione 1989; Rash et al., 2001). There was good general acceptance of the tests at the flight line as evidenced by the large amount of data contributed by the aviators. Despite the large amount of data collected, it remains unclear if the changes seen in pupillary response and self-reported increases in fatigue were effects of helicopter flight, the use of the IHADSS, or an interaction of both. In order to determine the contribution of these variables, a similar study is ongoing using UH-60 Blackhawk pilots. The Blackhawk does not use a monocular sighting system like that employed in the AH-64 Apache. This additional research should provide the information necessary to determine if the changes were due to the flight environment or use of the monocular sighting system.

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